Chapter 11 ELECTROSTATICS

INTRODUCTION:

⇒ Electro: a combining form representing **electric,** or **electricity.** Where the origin of the word is "from Latin *ēlectrum* amber, from Greek *electron*".

⇒ Statics mean anything at rest.

⇒ **Electrostatics** is a branch of physics that deals with study of the electric charges at rest.

⇒ Since classical physics, it has been known that some materials such as amber attract lightweight particles after rubbing. The Greek word for amber, ἤλεκτρον, or *electron*, was the source of the word 'electricity'.

⇒ Electrostatic phenomena arise from the forces that electric charges exert on each other. Such forces are described by Coulomb's law. Even though electrostatically induced forces seem to be rather weak, some electrostatic forces such as the one between an electron and a proton, that together make up a hydrogen atom, is about 36 orders of magnitude stronger than the gravitational force acting between them.

⇒ There are many examples of electrostatic phenomena, from those as simple as the attraction of the plastic wrap to your hand after you remove it from a package to the apparently spontaneous explosion of grain silos, the damage of electronic components during manufacturing, and photocopier & laser printer operation.

⇒ Electrostatics involves the buildup of charge on the surface of objects due to contact with other surfaces.

⇒ One of the primary questions to be asked in this unit How can an object be charged and what affect does that charge have upon other objects in its vicinity? The answer to this question begins with an understanding of the structure of matter. Understanding charge as a fundamental quantity demands that we have an understanding of the structure of an atom. So, we begin this unit with what might seem to many students to be a short review of a unit from a Chemistry course.

STRUCTURE OF ATOM:

⇒ The search for the atom began as a philosophical question.

⇒ It was the natural philosophers of ancient Greece that began the search for the atom by asking such questions as: What is *stuff* composed of? What is the structure of material objects? Is there a basic unit from which all objects are made?

⇒ As early as 400 B.C., some Greek philosophers proposed that matter is made of indivisible building blocks known as **Atomos.** (*Atomos* in Greek means indivisible.)

⇒ To these early Greeks, matter could not be continuously broken down and divided indefinitely. Rather, there was a basic unit or building block that was indivisible and foundational to its structure. This indivisible building block of which all matter was composed became known as the atom.

⇒ The early Greeks were simply philosophers. They did not perform experiments to test their theories.

⇒ In fact, science as an experimental discipline did not emerge as a credible and popular practice until sometime during the 1600s.

⇒ So the search for the atom remained a philosophical inquiry for a couple of millennia. From the 1600s to the present century, the search for the atom became an experimental pursuit.

⇒ Several scientists are notable; among them are Robert Boyle, John Dalton, J.J. Thomson, Ernest Rutherford, and Neil's Bohr.

i. BOYLE:

⇒ Boyle's studies (middle to late 1600s) of gaseous substances promoted the idea that there were different types of atoms known as elements.

ii. JOHN DALTON:

⇒ Dalton (early 1800s) conducted a variety of experiments to show that different elements can combine in fixed ratios of masses to form compounds.

⇒ Dalton subsequently proposed one of the first theories of atomic behavior that was supported by actual experimental evidence.

iii. JJ THOMSON ATOMIC MODEL:

⇒ English scientist J.J. Thomson's cathode ray experiments (end of the 19th century) led to the discovery of the negatively charged electron and the first ideas of the structure of these indivisible atoms.

⇒ Thomson proposed the *Plum Pudding Model*, suggesting that an atom's structure resembles the favorite

⇒ English dessert - plum pudding. The raisins dispersed amidst the plum pudding are analogous to negatively charged electrons immersed in a sea of positive charge. (same like the dry fruits are emersed in the custard, if we consider the dry fruits to be electron and custard as a atom.

iv. RUTHERFORD'S MODEL:

⇒ Nearly a decade after Thomson, Ernest Rutherford's famous gold foil experiments led to the nuclear model of atomic structure.

⇒ Rutherford's model suggested that the atom consisted of a densely packed core of positive charge known as the **nucleus** surrounded by negatively charged electrons.

⇒ While the nucleus was unique to the Rutherford atom, even more surprising was the proposal that an atom consisted mostly of empty space. Most the mass was packed into the nucleus that was abnormally small compared to the actual size of the atom.

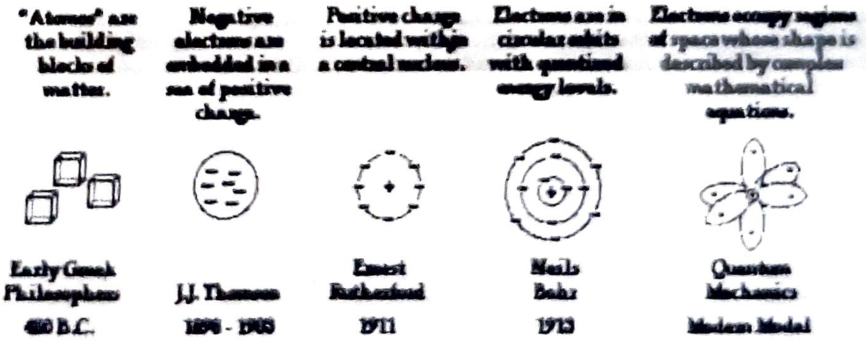
v. NEILS BOHR ATOMIC MODEL:

⇒ Neil's Bohr improved upon Rutherford's nuclear model (1913) by explaining that the electrons were present in orbits outside the nucleus.

⇒ The electrons were confined to specific orbits of fixed radius, each characterized by their own discrete levels of energy.

⇒ While electrons could be forced from one orbit to another orbit, it could never occupy the space between orbits.

Our Changing View of the Atom



⇒ Bohr's view of quantized energy levels was the precursor to modern quantum mechanical views of the atoms.

⇒ The mathematical nature of quantum mechanics prohibits a discussion of its details and restricts us to a brief conceptual description of its features.

⇒ Quantum mechanics suggests that an atom is composed of a variety of subatomic particles.

⇒ The three main subatomic particles are the proton, electron and neutron.

⇒ The proton and neutron are the most massive of the three subatomic particles; they are located in the nucleus of the atom, forming the dense core of the atom.

⇒ The proton is charged positively. The neutron does not possess a charge and is said to be neutral

⇒ The protons and neutrons are bound tightly together within the nucleus of the atom.

⇒ Outside the nucleus are concentric spherical regions of space known as **electron shells**.

⇒ The shells are the home of the negatively charged electrons.

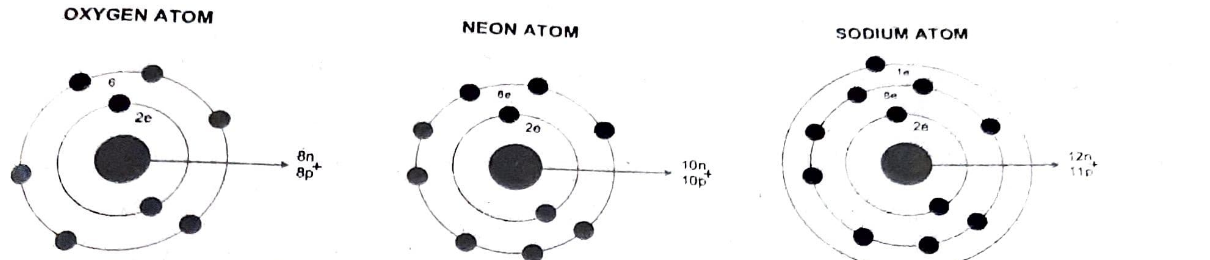
⇒ Each shell is characterized by a distinct energy level.

⇒ Outer shells have higher energy levels and are characterized as being lower in stability.

⇒ Electrons in higher energy shells can move *down* to lower energy shells; this movement is accompanied by the release of energy.

⇒ Similarly, electrons in lower energy shells can be induced to move to the higher energy outer shells by the addition of energy to the atom.

⇒ If provided sufficient energy, an electron can be removed from an atom and be freed from its attraction to the nucleus.



Atoms are composed of proton and neutrons and located in the nucleus and electrons which are positioned in the surroundings regions of space known as shells.

APPLICATION OF ATOMIC STRUCTURE TO ELECTROSTATICS:

This brief excursion into the history of atomic theory leads to some important conclusions about the structure of matter that will be of utmost importance to our study of static electricity. Those conclusions are summarized here:

i. All material objects are composed of atoms. There are different kinds of atoms known as elements; these elements can combine to form compounds. Different compounds have distinctly different properties. Material objects are composed of atoms and molecules of these elements and compounds, thus providing different materials with different electrical properties.

ii. An atom consists of a nucleus and a vast region of space outside the nucleus. Electrons are present in the region of space outside the nucleus. They are negatively charged and weakly bound to the atom. Electrons are often removed from and added to an atom by normal everyday occurrences. These occurrences are the focus of this Static Electricity unit.

iii. The nucleus of the atom contains positively charged protons and neutral neutrons. These protons and neutrons are not removable or perdurable by usual everyday methods. It would require some form of high-energy nuclear occurrence to disturb the nucleus and subsequently dislodge its positively charged protons. These high-energy occurrences are fortunately not an everyday event and they are certainly not the subject of this unit. One sure truth of this unit is that the protons and neutrons will remain within the nucleus of the atom. Electrostatic phenomenon can never be explained by the movement of protons.

SUMMARY

Sub atomic particles	LOCATION	STRENGTH	CHARGE	MASS
ELECTRON	Outside nucleus	Weakly bound	Negative charge	Not very massive
PROTON	Inside nucleus	Tightly bound	Positive charge	Massive
NEUTRON	Inside nucleus	Tightly bound	No charge	Massive

CHARGE objects, NEUTRAL objects, POSITIVE & NEGATIVE charge:

⇒ As discussed above that atoms are the building blocks of matter.

⇒ There are different types of atoms, known as elements. Atoms of each element are distinguished from each other

⇒ An atom containing 6 protons is a carbon atom. And an atom containing 8 protons is an oxygen atom.

⇒ The number of electrons that surround the nucleus will determine whether or not an atom is electrically charged or electrically neutral.

⇒ The amount of charge on a single proton is equal to the amount of charge possessed by a single electron.

- ⇒ A proton and an electron have an equal amount but an opposite type of charge. Thus, if an atom contains equal numbers of protons and electrons, the atom is described as being **electrically neutral**.
- ⇒ On the other hand, if an atom has an unequal number of protons and electrons, then the atom is electrically charged (and in fact, is then referred to as an **ion** rather than an atom).
- ⇒ Any particle, whether an atom, molecule or ion, that contains less electrons than protons is said to be **positively charged**.
- ⇒ Conversely, any particle that contains more electrons than protons is said to be **negatively charged**.

OBJECTS CHARGES WHEN THERE IS IMBALANCE OF ELECTRONS OR PROTONS:

- ⇒ An atom was described as being a small and dense core of positively charged protons and neutral neutrons surrounded by shells of negatively charged electrons.
- ⇒ The protons are tightly bound within the nucleus and not removable by ordinary measures.
- ⇒ While the electrons are attracted to the protons of the nucleus, the addition of energy to an atom can *persuade* the electrons to leave an atom.
- ⇒ Similarly, electrons within atoms of other materials can be *persuaded* to leave their own electron shells and *become members* of the electron's shells of other atoms of different materials. In short, electrons are migrants - constantly on the move and always ready to try out a new atomic environment.
- ⇒ All objects are composed of these atoms. The electrons contained within the objects are prone to move or migrate to other objects.
- ⇒ The process of an electron leaving one material object to reside (perhaps only temporarily) in another object is a common everyday occurrence.
- ⇒ If you were to walk across the carpeting towards the door of the room, electrons would likely be scuffed off the atoms of your shoes and moved onto the atoms of the carpet. And as clothes tumble in the dryer, it is highly likely that electrons on one piece of clothing will move from the atoms of the clothing onto the atoms of another piece of clothing. In general, for electrons to make a move from the atoms of one material to the atoms of another material, there must be an energy source, a *motive*, and a low-resistance *pathway*.
- ⇒ The cause and mechanisms by which this movement of electrons occurs will be the subject of chapter 12 (CURRENT ELECTRICITY).
- ⇒ Charged objects have an imbalance of charge - either more negative electrons than positive protons or vice versa.
- ⇒ And neutral objects have a **balance of charge - equal numbers of protons and electrons**. The principle stated earlier for atoms can be applied to objects.
- ⇒ ***If we add electrons to a neutral object it gets negatively charged.***
- ⇒ Objects with more electrons than protons are charged negatively; objects with fewer electrons than protons are charged positively.
- ⇒ In this discussion of electrically charged versus electrically neutral objects, the neutron has been neglected. Neutrons, being electrically neutral play no role in this unit. Their presence (or absence) will have no direct bearing upon whether an object is charged or uncharged. Their role in the atom is merely to provide stability to the nucleus, a subject not discussed here. When it comes to the drama of static electricity, electrons and protons become the main characters.

Charge as a Quantity

- ⇒ Like mass, the charge of an object is a measurable quantity.
- ⇒ The charge possessed by an object is often expressed using the scientific unit known as the **Coulomb**.
- ⇒ Just as mass is measured in grams or kilograms, charge is measured in units of Coulombs (abbreviated C). Because one Coulomb of charge is an abnormally large quantity of charge, the units of microcoulombs (µC) or nanocoulombs (nC) are more commonly used as the unit of measurement of charge.
- ⇒ To illustrate the magnitude of 1 Coulomb, an object would need an excess of 6.25×10^{18} electrons to have a total charge of -1 C. And of course, an object with a shortage of 6.25×10^{18} electrons would have a total charge of +1 C.
- ⇒ The charge on a single electron is -1.6×10^{-19} Coulomb.

- ⇒ The charge on a single proton is $+1.6 \times 10^{-19}$ Coulomb.
- ⇒ The quantity of charge on an object reflects the amount of imbalance between electrons and protons on that object. Thus, to determine the total charge of a positively charged object (an object with an excess of protons), one must subtract the total number of electrons from the total number of protons. This operation yields the number of excess
- ⇒ Since a single proton contributes a charge of $+1.6 \times 10^{-19}$ Coulomb to the overall charge of an atom, the total charge can be computed by multiplying the number of excess protons by $+1.6 \times 10^{-19}$ Coulomb.
- ⇒ A similar process is used to determine the total charge of a negatively charged object (an object with an excess of electrons), except that the number of protons is first subtracted from the number of electrons.

Object	No Excess Protons/Electrons	Quantity and Kind of Charge (Q) on Object in Coulombs (C)
A	1×10^{6} *excess electrons*	$-1.6 \times 10^{-13}\ C$
B	1×10^{6} *excess protons*	$+1.6 \times 10^{-13}\ C$
C	2×10^{10} *excess electrons*	$-3.2 \times 10^{-9}\ C$
D	3.5×10^{8} *excess protons*	$+5.6 \times 10^{-11}\ C$
E	4.67×10^{10} *excess electrons*	$-7.5 \times 10^{-9}\ C$

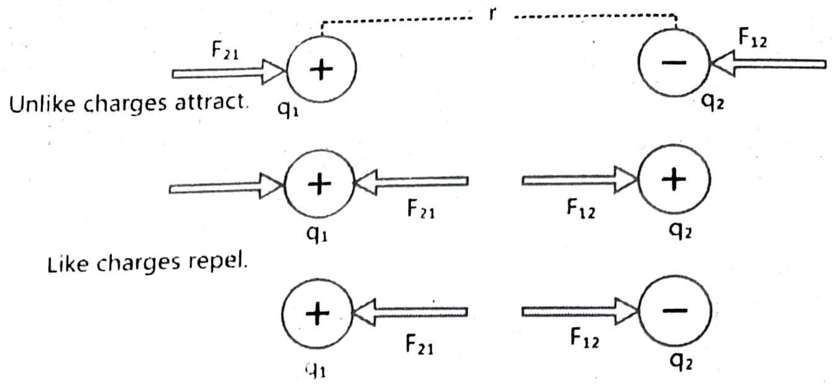
- ⇒ In contrast, a charged object has an imbalance of protons and electrons.
- ⇒ Determining the quantity of charge on such an object involves a *counting process*; the total number of electrons and protons are compared to determine the difference between the number of protons and electrons.
- ⇒ This difference is multiplied by 1.6×10^{-19} Coulombs to determine the overall quantity of charge on the object.
- ⇒ The type of charge (positive or negative) is determined by whether the protons or the electrons are in excess.

Charge Interactions

- ⇒ Suppose that you rubbed a balloon with a sample of animal fur such as a wool sweater or even your own hair.
- ⇒ The balloon would likely become charged and its charge would exert a strange influence upon other objects in its vicinity. If some small bits of paper were placed upon a table and the balloon were brought near and held above the paper bits, then the presence of the charged balloon might create a sufficient attraction for the paper bits to raise them off the table. This influence - known as an **electric force** - occurs even when the charged balloon is held some distance away from the paper bits.
- ⇒ The electric force is a non-contact force.
- ⇒ Any charged object can exert this force upon other objects - both charged and uncharged objects.

Opposites attract. And likes repel

- ⇒ These two fundamental principles of charge interactions will be used throughout the unit to explain the vast array of static electricity phenomena.
- ⇒ There are two types of electrically charged objects - those that contain more protons than electrons and are said to be positively charged and those that contain less protons than electrons and are said to be negatively charged.
- ⇒ These two types of electrical charges - positive and negative - are said to be opposite types of charge.
- ⇒ And consistent with our fundamental principle of charge interaction, a positively charged object will attract a negatively charged object.
- ⇒ Oppositely charged objects will exert an attractive influence upon each other. In contrast to the attractive force between two objects with opposite charges, two objects that are of like charge will repel each other.
- ⇒ That is, a positively charged object will exert a repulsive force upon a second positively charged object. This repulsive force will push the two objects apart.
- ⇒ Similarly, a negatively charged object will exert a repulsive force upon a second negatively charged object. Objects with like charge repel each other.



Type of interaction	*Result*
Like charges	Repulsion
Unlike charges	Attraction

Some Basic Definitions	
Composite particles	Those particles which are made up of some other particles. Like Atoms etc..
Elementary Particles	Those particles which are not made up of other particles. Like Electron etc..
Charge	An intrinsic property carried by Elementary, conserved and Quantized particles is called charge.
Types of charge **Charge are of 2 types**	Positive charge: when we remove electron from something then there appear positive charge, or when substance loses electrons there appears positive charge. Negative charge: when object gains electrons there appears negative charge.
Charge or electrified Body	When a body has deficiency or excess of electrons from the normal due share then it is said to be charged or electrified body.

Some numerical data	
Smallest charge in universe	$1.6 \times 10^{-19}C$
Charge on electron	$-1.6 \times 10^{-19}C$
Charge on proton	$+1.6 \times 10^{-19}C$
Magnitude of charge on proton	$1.6 \times 10^{-19}C$
Magnitude of charge on electron	$1.6 \times 10^{-19}C$

Because magnitude can never be negative.

Nature of electricity

We know that matter as a whole neutral in nature, and matter contain particles of electricity which are nothing but electron and protons, so whether a given body will show electricity i.e. charge or not depends upon the relative numbers of these particles in a body.

$if\ no\ proton = no\ of\ electron$	$charge\ on\ body = 0$	Example: paper of this book.
$no\ of\ proton > no\ of\ electron$	$Charge\ on\ body = +ve$	
$no\ of\ electron > no\ of\ proton$	$Charge\ on\ body = -ve$	
Under normal conditions Charge on body	$\boldsymbol{no\ of\ electron = no\ of\ proton \rightarrow Charge = 0}$	

Conceptual: Why in definition of charge electron is used, why not proton, because both are quantized, conserved and elementary particles?

Answer: Because electrons are very mobile and can be easily removed. However, protons are held very powerfully in nucleus and cannot be removed.

History of charges:

⇒ If a glass rod is rubbed with silk or cotton some electrons passed from glass rod to silk. As a result, the glass rod becomes positively charges and silk attain an equal amount of negative charge. This is because the silk

gains an equal number of electrons that are lost by glass rod. Above we have discussed that "***Like charge repel, & Unlike charges attract each other***".

⇒ So if on glass rod positive charge appears and on silk negative charge appear they will attract each other.

⇒ If different materials are used then there will be attraction.

⇒ If same material is used like, 2 glass rods of same nature, then in this case there will be repulsion.

Summary (Important points):

- By rubbing no charge produced, but there is transfer of electron from one body to other body.
- Electrons transferred from glass rod to silk due to rubbing because we have done external work upon it. Thus, law of conservation of energy holds good.
- As mass of electron is ~~greater~~ less than mass of proton so there will increase in mass of silk and mass of glass rod will decrease. So, law of conservation of mass holds.

Frictional Electricity: the electrostatic charges i.e.... charges at rest produced on insulating bodies when they are rubbed against each other is called *frictional electricity*.

- So, when glass rod rubbed with cloth or silk this type of electricity developed.

In the table given below, if a body in the first column is rubbed against a body in the second column, the body in first column will acquire positive charge, while that in the second column will acquire negative charge.

S-NO	First column	Second Column
1.	Glass rod	Silk rod
2.	Flannes or Cat skin	Ebonite rod
3.	Woolen cloth	Amber
4.	Woolen cloth	Rubber shoes
5.	Woolen cloth	Plastic objects

MCQ: NOTE that human body and earth are good conductor of electricity.

Conductors and Insulators

In general, substance is divided in to two types on the basis of their ability to conduct electricity;

Conductors

✓ Those substance through which *electric charge can flow easily* is called conductors.

✓ Those substance ***which have free electrons.***

✓ Example: silver, copper, aluminum, mercury etc...

✓ In metallic conductors. charge carriers are electrons.

✓ In liquid conductors, charge carrier is both positive and negative ions.

Insulators

✓ Those substance which ***do not have free electrons***.

✓ Those substance through which *electric current cannot be passed.*

✓ When such materials are charged by *rubbing*, then only the area that is rubbed becomes charged and there is no tendency of charge to move into other regions.

✓ Some common insulators are glass, air, plastic, rubber, and wood.

Summary

⇒ For Insulator ⇒ $q_{induced} < q$

⇒ For Conductor ⇒ $q_{induced} = q$

⇒ $q_{induced} > q$ ⇒ it is impossible

Important points:

i. When charge is placed on insulator say by rubbing it stays in region where it has been placed.

ii. But when charge placed on metal surface, then it is quickly redistributed over the entire surface of the metal.

iii. This difference is due to metals are conductors and have free electrons, on the other hand insulator do not have free electrons.

iv. So, hand held metal cannot be charged by rubbing.

Electrification:

- ⇨ Charging of a body is called electrification.
- ⇨ Charging of body may takes place through
  - i) By conduction
  - ii) By Induction

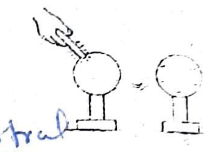
Different methods of charging

If conductor is initially uncharged then it can be charged through following methods.

1) By conduction
2) By induction

We will discuss each method in detail.

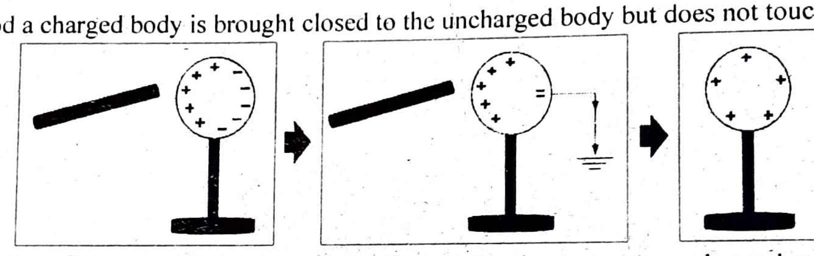
1. By conduction:



- ✓ In this method a charged body is brought in physical contact with the uncharged conductor.
- ✓ In given figure if negative charged object comes in contact with neutral object then ~~negative~~ Neutral object get electrons from negative charge particles. in this way some negative charge transfer from negative charge object to neutral object. and this is done when they are in contact with each other so we can say that neutral object gets charged by conduction.

2. By induction:

- ✓ In this method a charged body is brought closed to the uncharged body but does not touch it.



- ✓ Figure above show that a negatively charged plastic rod when kept near an uncharged metal sphere. The free electrons of the sphere near the plastic rod are repelled to the farther end. As a result the region of the sphere near the rod becomes positively charged and the second end of the sphere becomes negatively charged.
- ✓ If now the sphere is connected to the ground through a wire as shown in figure 2 above, its free electrons at the other ends flow to the ground and then on removing the wire to the ground the positive charge at the near end sphere remains held there due to attractive forces of external negative charge.
- ✓ Finally, when the plastic rod is removed the positive charge spread uniformly on the sphere.
- ✓ So, sphere becomes positively charged by induction.
- ✓ But note that in whole process the negatively charges plastic rod losses no negative charge.

Unit of electric charge

- ⇒ Previously we know that positive charge show deficiency of electrons and negative charge shows excess of electrons from the normal due share.
- ⇒ So, we can say that charge on electron is very small.
- ⇒ It is not convenient to select it as the unit of charge, in practice coulomb is used as the unit of charge.
- ⇒ SI unit of charge is coulomb, represented by C.
- ⇒ One coulomb of charge is equal to charge of 6.25×10^{16} electrons.

$$1\ coulomb = charge\ on\ 6.25 \times 10^{16}\ electrons$$

Concept:
So, a body has a positive charge of one coulomb (i.e. +1C), it means that a body has deficit of 6.25×10^{16} *electrons*.

$$so\ charge\ on\ 1\ electron\ in\ coloumb \Rightarrow -e = \frac{1}{6.25 \times 10^{16}} = 1.6 \times 10^{-19} C$$

- Charge on electron has been determined experimentally by RA Millikan
- In CGS units, charge on electron is $4.80320425(10) \times 10^{-10}$ stat coulombs.

Properties of charge

2. Add...
3. Conservation of electric charge.

S-N	Property	Description
1.	***Quantization of charge***	✓ We know that charge on electron ($-e = -1.6 \times 10^{-19}C$) or on proton ($e = +1.6 \times 10^{-19}C$) is minimum. ✓ We also know that charge on a body is due to loss or gain of electrons, and also a body cannot loss or gain friction of electron, so the charge on a body must be integral multiple of electronic charge $\pm e$. ✓ So, charge on a body can only be; $$Q = \pm ne$$ $where\ n = 1,2,3, \dots and\ e = 1.6 \times 10^{-19}C$ This is actually called "Quantization of charge". ✓ This property shows that charge is discrete in nature not continuous in nature. ✓ We normally do not notice its discreetness in macroscopic charge $1\mu C\ charge\ requires\ 10^{13} electrons\ which\ thus\ seem\ continous.$ ***MCQ:*** Let say you measure charge on a tiny object is $+4.3 \times 10^{-19}C$, this measurement is not correct because measured value is not an integral multiple of minimum charge $1.6 \times 10^{-19}C$, the correct value will be $+4.8 \times 10^{-19}C$ (i.e. 3e) ***MCQ:*** When a physical quantity (electric charge) can ha a certain value rather than any value we say that a quantity is quantized. Thus, a body may have a positive charge +10e but not +9.5, and also a body may have a negative charge – 15e but not -14.5e
2.	***Additive nature of charge***	✓ We know that electric charge is a scalar quantity, it has magnitude but no direction. ✓ So, the total charge on a body or a system is equal to algebraic sum (i.e. sum taking in account positive and negative sign) of all individual electric charges on the body. ✓ So, the total charge on a body is equal to algebraic sum of all charges located at different parts of body. ✓ If ***n charges*** exists on a body $q_1, q_2, q_3 \cdots q_n$ are present on different parts of body then total charge Q on a body I given by; $$Q = ((q_1) + (q_2) + \cdots (q_n))$$
3.	***Conservation of electric charge***	✓ This shows that total charge of an isolated system remains constant. And is called law of conservation of charges. ✓ Charge can neither created nor destroyed but it can be transfer from one body to another body. ✓ Just like linear momentum which is constant throughout, same charge of an isolated system remains constant. ✓ Remember that no violation of this law has ever been found and it is firmly established as the law of conservation of linear momentum and energy. ✓ In electrostatics an isolated system can be defined as; a system in which there is no external

		disturbance i.e. there is no leakage of charge.

TRICK
Sometime is MCQ they relate magnitude of charge with speed of a body, but remember that magnitude of charge is independent of speed of charge.

Important

No Of Electron in 1 Coloumb:

$$q = ne \Rightarrow n = \frac{q}{e} \Rightarrow \frac{1C}{1.6 \times 10^{-19}C} \Rightarrow n = 6.25 \times 10^{18}e$$

$$so\ n = N(6.25 \times 10^{18}e)$$

$$n = No\ of\ electrons$$

$$N = No\ of\ charges$$

Neutralization of charge:

⇒ We know that the rule of nature is "everything moves from the region of higher concentration to the region of lower concentration".
⇒ In same way charges always flow from the region of higher potential to the region of lower potential.
⇒ In the same way here new concept arises, that is neutralization Of charges.
⇒ Neutralization is derived from neutral.
⇒ So, it means that if we have two charge body connected to each other, then the flow of charges will be continued up to a limit, until the charge density becomes equal.
⇒ If charge density is same than there will be no flow of charges.
⇒ So at last we can concludes that the charge always flow from the region of higher concentration too the region of lower concentration.

Important Points

⇒ Like charged bodies may attract each other.
⇒ Attraction also takes place between charged and neutral body.
⇒ Electrostatic force of interaction is conservative in nature.
⇒ The work done by electrostatic force does not depend upon path. It only depends upon initial and final positions.
⇒ In a closed path work done by electrostatic force is zero.
⇒ No relativistic variation is found in electric charge.
⇒ The transfer of charge without mass is not possible.
⇒ The transfer of mass without charge is possible.
⇒ Massless particle (e.g., photon) never be charged.
⇒ Charging by induction takes place without any loss of charge from the charging body.
⇒ The magnitude of induced charge is always less or equal to charging body.
⇒ Electrostatic induction does not take place between point charges.
⇒ Electrostatic induction only takes place between bodies of definite shape (either conducting or non-conducting.)
⇒ Charges will always flow from higher concentration (potential) to lower concentration (potential).

Types of charges

i. Test charge
ii. Source charge
iii. Point charge

i) Test charge:

⇒ The test charge is a charge that is used to test or study effect or field strength of another charge.
⇒ Primary source is always test charge.
⇒ It is represented by q_o

ii) Source charge:

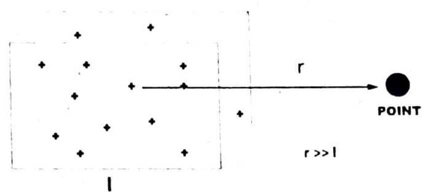
⇒ A charge whose field strength are under observation or under study.
⇒ Field strength of a source charge can be studied with the help of another charge that is called test charge.
⇒ Note that electric field can be observed in the presence of another electric field.
⇒ It is generally represented by "q".

$$\text{Note that } q \gg q_o$$

Magnitude of source charge is so greater thatn that of test charge.

iii) Point charge:

⇒ Point charge is the distance between a point whose field strength is observing and charge is much greater than the dimension (such as length, area and volume) of charges, than this charge will be called point charge.
⇒ Or simply it is the distance between two charge that is very large as compared to the dimension of charges.
⇒ Represented by ρ.



Charge density

⇒ Magnitude of charge per unit dimension (length, area and volume)
⇒ There are three (3) types of charge density;

i. Linear charge density: (magnitude of charge per unit length) $\rho_l = \frac{charge}{length} = \frac{q}{l}$.

Charge distributed on a cylinder or rod

ii. Surface charge density: (magnitude of charge per unit area) $\rho_A = \frac{charge}{area} = \frac{q}{A}$.

Charge ditributed on sheet

iii. Volume charge density: (magnitude of charge per unit volume) $\rho_v = \frac{q}{volume}$

Charge distributed on cube

One most Important concept is:

What is actually Uniform Charge density:

⇒ If charge density is constant then it is called uniform charge density.
⇒ As the word uniform stand for constant.
⇒ It means that in all region the charge magnitude is same, in case of uniform charge or uniform charge density.
⇒ This word is most important and examiners also use this word in MCQs, so if you find in MCQs the word uniform it means that the magnitude of charge is same everywhere.

Difference between Electric charge and Mass

S-N	Electric charge	Mass
1.	It may be positive, negative or even zero. Depend upon the case	Mass of a body is always a positive.
2.	It is quantized quantity.	Quantization of mass is impossible.
3.	Magnitude of charge is independent of speed.	Magnitude of mass increases with increase in the speed of body, that is related to relativity, we will study it in Dawn of modern physics.
4.	Force between two charges may be attractive, repulsive.	Force between two masses is always attractive.
5.	Forces between different charges may cancel out.	It always cancels out.

If we supply a charge to a soap bubble then it will expand. Why?

Since we know like charges repel and try to get away from each other which is at outer surface of the conductor. So, a soap bubble expands.

Some basic definitions:

i. ***Dielectric:*** A substance having two poles formed during polarization in the presence of electric field. Every dielectric is insulator but every insulator is not dielectric.

ii. ***Permittivity:*** the property of medium to be polarize in the presence of electric field, or it is the capability of medium to allow field lines by medium between two charges to interact.

- Permittivity of air or vacuum is represented by ε_o.
- Air or vacuum has a minimum value of permittivity.
- The absolute or actual permittivity of air or vacuum is;

$$(8.854 \times 10^{-12} C^2 N^{-1} m^{-2})$$

- The absolute permittivity of all other insulating materials is greater than ε_o.
- Absolute Permittivity itself is represented by represented by ε.

iii. Relative permittivity or Dielectric constant:

Concept i:

- The ratio of $\frac{\varepsilon}{\varepsilon_o}$ of material is called relative permittivity of the material.
- generally denoted by 'k' or (ε_r).

$$k \text{ or } \varepsilon_r = \frac{Absolute\ permitivity\ of\ medium}{Absolute\ permitivity\ of\ air\ or\ vacuum}$$

- Note that relative permittivity is also called Dielectric constant.

Concept ii:

- Force between two charges in air or in vacuum (will be discuss in coulomb's law) is given by;

$$F = \frac{1}{4\pi\epsilon_o}\frac{q_1 q_2}{r^2}$$

Force between same two charges held same distance apart in a medium of absolute permitivity is given by;

$$F_m = \frac{1}{4\pi\epsilon}\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\epsilon_o k}\frac{q_1 q_2}{r^2}$$

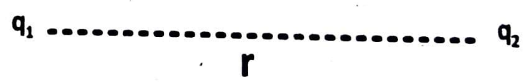
$$\therefore \frac{F_{air}}{F_{medium}} = \frac{\epsilon}{\epsilon_o} = k = relative\ permitivity\ of\ medium$$

So, the ratio of force between two charges separated by certain distance in air or vacuum to the same charges separated by same distance in the medium.

Coulomb's Law

⇒ This law is applicable for point charges.

⇒ This law is also called 'Action at a distance law'.



⇒ **Statement;** 'Force between two-point charges is directly proportional to the product of their magnitudes and inversely proportional to the square of distance between their centers.

⇒ The force will be *attractive or repulsive* it depends upon whether the charges are alike or not.

$$F \propto \frac{q_1 q_2}{r^2}$$

⇒ **Scalar form of Coulomb's law;**

$$K = k\frac{q_1 q_2}{r^2}$$

⇒ K is constant of proportionality also called ***electrostatic force constant.***

⇒ The value of k depends upon nature of medium and system of units.

⇒ When the charges are situated in free space (air/vacuum) then Si unit for value of k is;

$$k = \frac{1}{4\pi\epsilon_o} \Rightarrow \frac{1}{4\pi \times 8.854 \times 10^{-12}} = 9 \times 10^9 Nm^2C^{-2}$$

⇒ ϵ_o is absolute permittivity of free space and its value being equal to

$$8.854 \times 10^{-12} C^2 N^{-12} m^{-2}$$

⇒ So, Coulomb's law when the medium is vacuum or air is given by;

$$F = \frac{1}{4\pi\epsilon_o}\frac{q_1q_2}{r^2} \text{ or } 9\times10^9\frac{q_1q_2}{r^2}$$

⇒ **Si unit of ϵ_o;**

$$F = \frac{1}{4\pi\epsilon_o}\frac{q_1q_2}{r^2} \Rightarrow \epsilon_o = \frac{1}{4\pi F}\frac{q_1q_2}{r^2}$$

$$\epsilon_o = \frac{1\ CC}{N\ m^2} = C^2N^{-1}m^{-2}$$

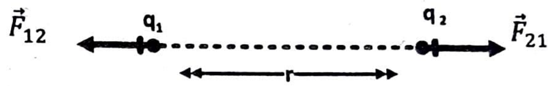
⇒ **C.G.S unit of k;** K in C.G.S system = 1e.s. u

⇒ **Dimension of ϵ_o;**

$$\epsilon_o = \frac{[AT][AT]}{[MLT^2][L^2]} = [M^{-1}L^{-3}T^4A^2]$$

⇒ **Coulomb's law in vector form;**

- For every action there will be equal but opposite reaction.
- This is in accordance with Newton's 3rd Law
- Coulomb's law in vector form is given by;



$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_o}\frac{q_1q_2}{r^2}\hat{r}_{12}$$

Or

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_o}\frac{q_1q_2}{r^2}\hat{r}_{21}$$

⇒ **Importance of Coulomb's law in vector form;**

- As the two forces shown by $\vec{F}_{21}$(*force by charge* 2 *on another*) and $\vec{F}_{12}$(*force by charge* 1 *on charge* 2) are equal in magnitude but are opposite in direction.

$$\vec{F}_{12} = -\vec{F}_{21}$$

Or

$$\vec{F}_{21} = -\vec{F}_{12}$$

Or

$$\hat{r}_{12} = -\hat{r}_{21}$$

Or

$$\hat{r}_{21} = -\hat{r}_{12}$$

Note that $\hat{r}_{21} \neq \hat{r}_{12}$ but $|r_{21} = r_{12}|$

- this means that these two forces by the same charges on each other act along the same line. Along the line joining q_1 *and* q_2.
- We can also say that electrostatic force between two charges is central force.
- However scalar form of Coulomb's law does not show this fact.
- Electrostatic force is a conservative force, work done by this force over a closed path is zero.

⇒ **Definition of 1 C from Coulomb's Law;**

$$\text{as;}\quad F = 9\times10^9\frac{q_1q_2}{r^2}$$

$$\text{if } q_1 = q_2 = 1C \text{ and } r = 1m, \text{ then; } F = 9\times10^9N$$

- Coulomb is very large unit of charge in the study of electrostatics.
- In practice charge are measures in smaller units like; 1 *pico − coulomb*, or $1\mu C$.
- One disadvantage of Si unit is that coulomb is very large unit of charge.

⇒ **Limitations of Coulombs law;**

i. *It is only applicable for stationary charges.*
ii. *The charges must be point charges.*
iii. *Force must be along the line joining two charges.*
iv. *When charge is subjected to motion there arises another field (magnetic field) which cannot be explained by coulomb's law.*

Important Points:

⇒ This ratio $k = \frac{\epsilon_o}{\epsilon_o} = 1$ for air or vacuum.

⇒ For all other insulating material except air or vacuum value of k is more than 1.

⇒ $F_m = \frac{F_{air}}{k}$ this shows that force between two charges is decreased when air is replaced by another insulating medium.

⇒ k *for water is* 80, what is actually means;

It means that for the same charges (q_1, q_2) *and same distance (r), the force between two charges in water is* $\frac{1}{80^{th}}$ *of that in air.*

⇒ 'k' is actually the number being the ratio of two absolute permittivity.

⇒ $\epsilon_r = \frac{\epsilon_m}{\epsilon_o}$

⇒ $\epsilon_r = \frac{F_{vac}}{F_{med}}$ $\quad F_{vac} \rightarrow Coulombic\ force.$

⇒ $\epsilon_r = \frac{K_{vac}}{K_{med}}$ $\quad K_{vac} = Coulombiicc\ constant.$

⇒ $\frac{k_{med}}{k_v} = \frac{1}{\epsilon_r} = \epsilon_r^{-1}$

⇒ $k_{medium} = \frac{k_{vacuum}}{\epsilon_r}$

⇒ $F_{medium} = \frac{F_{vacuum}}{\epsilon_r} \Rightarrow \epsilon_r = \frac{F_{vacuum}}{F_{medium}} \rightarrow$

$The\ ratio\ of\ two\ forces\ when\ there\ is\ no\ medium\ to\ the\ ratio\ of\ force\ when\ there\ is\ medium = \epsilon_r$

⇒ $\epsilon_{medium} = \epsilon_r \epsilon_o$

⇒ $F_{vacuum} = \epsilon_r F_m \Rightarrow F_{vacuum} > F_{medium}$

⇒ $F_{medium} \propto \frac{1}{\epsilon_o}$

Critical points

1) When the distance between the two charges placed in vacuum or a medium is increased K-times then the force between them decreases K^2 -times. i.e.. if F_0 and F be the initial and final forces between them, then

$$F = \frac{F_o}{K^2}$$

2) When the distance between the two charges placed in vacuum or a medium is decreased K-times then the force between them increases K^2 -times. i.e., if F_o and F be the initial and final forces then

$$F = k^2 F_o$$

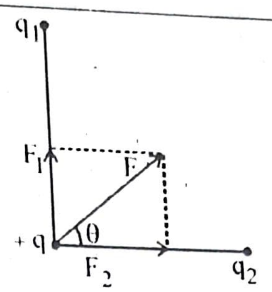
3) When a medium of dielectric constant K is placed between the two charges then the force between them decreases by K-times. i.e., if F_o and F be the forces in vacuum and the medium respectively, then

$$F = \frac{F_o}{K}$$

4) When a medium of dielectric constant K between the charges is replaced by another medium of dielectric constant K' then the force decreases or increases by (K/K') times according as K' is greater than K or K' is less than K.

Force on one charge due to two other charges:

Resultant force on q due to q_1 and q_2 are obtained by vector addition of individual forces



$$\vec{F} = \vec{F_1} + \vec{F_2}$$

$$|\vec{F}| = \sqrt{|\vec{F_1}|^2 + |\vec{F_2}|^2}$$

Questions:

Electric force between two-point charges q and Q at rest is F. Now if a charge – q is placed next to q what will be the

(a) force on Q due to q

(b) total force on Q?

SOLUTION:

(a) As electric force between two body interaction, i.e., force between two particles, is independent of presence or absence of other particles, the force between Q and q will remain unchanged, i.e., F

(b) An electric force is proportional to the magnitude of charges, total force on Q will be given by

$$\frac{F'}{F} = \frac{Qq'}{Qq} = \frac{q'}{q} = \frac{0}{q} = 0 \quad \{As\ q' = q + (-q) = 0\}$$

i.e., the resultant or total force on Q will be zero.

Electric field

⇒ Faraday gives us concept of electric field.

⇒ Electric field is ***<u>Real field</u>***.

⇒ Electric field is actually the region or space around a source charge where test charge can experience force.

⇒ It is vector field, because it has magnitude and direction.

⇒ Magnitude is given by; force per unit charge $(\frac{F}{q})$.

⇒ Direction is given by; direction of force on a test charge.

⇒ It has single direction at a single point.

⇒ But for different points different directions are possible.

⇒ Theoretically electric field extends up-to infinity.

⇒ But however, the effect of electric field dies quickly at the distance from the charge is increased.

⇒ It may be noted that the electric field should not be thought of as a kind of matter. it is a concept invented by human to analyze the electrostatics phenomena.

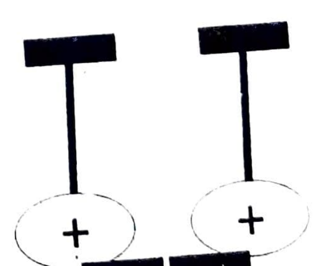
What produces Electrostatic force between two charges?

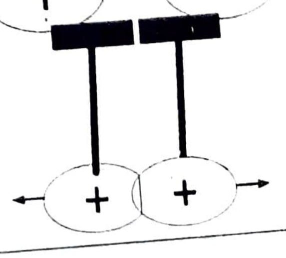
Faraday shows that between two charges, there is special type of interaction that is called field-field interaction. this interaction is responsible for electrostatic (attractive or repulsive) force.

Some cases;

Case 1st:

If two field do not overlap each other or if there is no interaction between two charges then there will be no force. **F = 0**.





Case 2nd:

If two fields overlap each other then surely there will be some electrostatic force, it may be attractive or repulsive depends upon the nature of source

and point charge. $F \neq 0$

Note that;

$$Force \propto Overlaping\ of\ two\ charges/\ Distortion\ of\ field$$

$$Force \propto magnitude\ of\ source\ charge$$

$$Force \propto \frac{1}{distance\ between\ two\ charges\ undergoing\ overlaping}$$

- ✓ When a charged particle moves perpendicular to a uniform magnetic field it follows a parabolic path in electric field.
- ✓ When a charged particle of charge +q is at rest or moving in the direction of electric field, it will experience a force $q\vec{E}$ in the direction of $\vec{E}$. As a result, the charged particle is accelerated in the direction of $\vec{E}$.
- ✓ When a charged particle of charge +q is moving opposite to the direction of electric field, it will experience a retarding force $-q\vec{E}$ *and hence the motion of a particle is retarded.*

Electric field strength / Intensity

⇒ It can be defined as 'the force experienced by unit positive charge placed at that point'.

$$E = \frac{F}{q_o}$$

In vector form;

$$\vec{E} = \frac{\vec{F}}{q_o}$$

⇒ Clearly the electric field strength (force/charge) is a vector, have magnitude as well as direction/

⇒ The direction of electric field is along the force that is experienced by a positive test charge.

⇒ Si unit is newton per coulomb (N/C).

⇒ The dimension of electric field strength is;

$$E = \frac{F}{q_o} \Rightarrow \frac{[MLT^{-2}]}{[A \times T]} \Rightarrow [MLT^{-3}A^{-1}]$$

⇒ The magnitude of q_o (test charge) must be small so that it does not affect other charge.

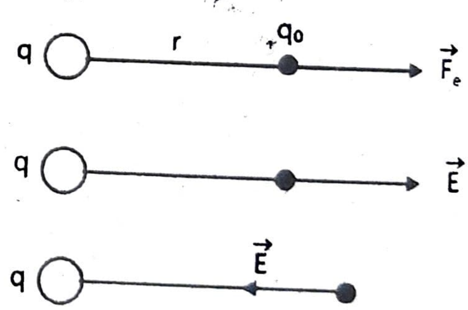
⇒ The equation $E = \frac{F}{q_o}$ is applicable for test charge.

Electric field intensity due to a point charge

⇒ The electric field intensity of a charge at a point at a distance r is given by;

$$\vec{E} = \frac{\vec{F}}{q_o} = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2}\hat{r}$$

$$|\vec{E}| = \frac{1}{4\pi\epsilon_m}\frac{q}{r^2} = \frac{1}{4\pi\epsilon_o\epsilon_r}\frac{q}{r^2} = k\frac{q}{r^2}$$



⇒ This equation is applicable for point charges.

⇒ This is actually coulomb's law in terms of electric field intensity.

⇒ Dependence of electric field intensity due to a point charge;

$$E \propto q$$

$$E \propto \frac{1}{r^2}$$

$$E \propto \frac{1}{\epsilon_m}$$

⇒ The magnitude of $\vec{E}$ depends upon the magnitude of charge +q which produce electric field and does not depends upon the value of test charge $+q_o$.

⇒ The electric field is a property of a space and not of the charge testing the field.

For example; if the test charge is ***doubled*** the electric force acting on it will be also ***doubled***, however the ratio $\frac{2F}{2q_o}$.

Concept;

Electric field intensity due to a point charge when there is medium is given by;

$$E_m = \frac{1}{4\pi\epsilon_r\epsilon_o}\frac{q}{r^2}$$

$$E_m = \frac{1}{\epsilon_o}\left|\frac{1}{4\pi\epsilon_o}\frac{q}{r^2}\right| \Rightarrow E_{medium} = \frac{1}{\epsilon_r}[\epsilon_{vacuum}] \Rightarrow E_{medium} = \frac{E_{vacuum}}{E_{relative}}$$

Or

$$E_{relative} = \frac{E_{vacuum}}{E_{medium}}$$ → *The ratio of electric field intensity in vacuum to electric field intensity whne there is medium is equal to* ϵ_r

Now we have two type of equation for finding Electric field strength:

1: $E = \frac{kq}{r^2}$ $q \rightarrow$ *Source charge*

only applicable for point charges

2: $E = \frac{F}{q_o}$ $q_o \rightarrow$ *Test charge*

Electric field lines

⇒ Electric field produced by charge or group of charges is represented by Electric field lines.

⇒ Or we can say that it is used to map or visualize field.

⇒ They are also known as "Electric lines of force".

⇒ The electric lines of force are path along which a small positive test charge would move free to do so.

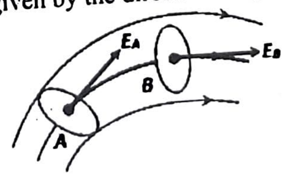
⇒ Sometimes they seem to be continuous but note that they are discrete in nature. They may be very close to each other but still there exist some gap. In short, they do not overlap each other.

⇒ They always originate from positive charge and ends on negative charge.

Some important	interpretations
+ source Charge	*Sink of electric field lines with reference to negative test charge*
−Source charge	*Source of electric field lines with reference to negative test charge*

Some important relationship between Electric field and Electric field lines:

- *Electric field lines* ∝ *magnitude of source charge.*
- There direction is same with electric field.
- The field lines may be straight or curved.
- The direction of $\vec{E}$ at any point is given by the direction tangent to the field line at that point.

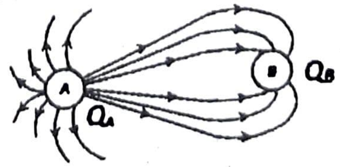


- The strength of electric field is determined by the separation of neighboring field lines.

  Field lines close to each other ⇒ *electric field strength* → *Large*

  Field lines far apart ⇒ *the field strength is* → *Weak*

- The number of lines originating or terminating on a charge is proportional to the magnitude charge. In the following figure electric lines of force are originating from A and terminatir hence Q_A is positive while Q_B is negative, also number of electric lines at force linked wit more than those linked with Q_B hence $|Q_A| > |Q_B|$



Why we need to represent electric field by electric field lines?

Answer: the representation of electric field by electric field lines allows us to infer relative field strength as well as the direction of the electric field.

Are Electric field lines being real?

Answer: Electric field lines do not actually exist, we use it to only represent an electric field. Certainly, it is useful method of visual representation of electric field, in fact it is great invention of human mind.

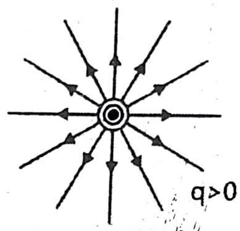
Some important properties of Electric lines of force:

- ✓ Electric field lines cannot pass through a conductor, this means that electric field inside conductor is zero.
- ✓ *Electric field lines of force can pass through a conductor.*
- ✓ Electric field lines have tendency to contract in length, this explains attraction between oppositely charged bodies.
- ✓ They have a tendency to expand laterally. i.e., they tend to separate from each other in the direction perpendicular to lengths, this explains repulsion between like charges.

Electric field lines due to some charge configurations:

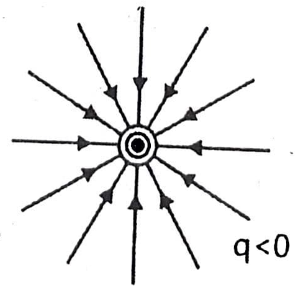
i. Single positive point charge
ii. Single negative point charge
iii. Two equal and opposite point charges
iv. Two equal positive point charges
v. Two unequal positive point charges
vi. Parallel plate capacitor

i. *Single positive point charge:*



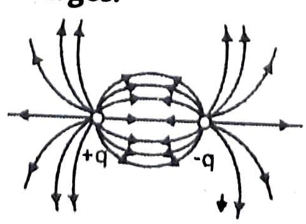
- ✓ In this case electric field lines are radially outward.
- ✓ This is expected because a small positive test charge would experience a force directed radially away from the positive point charges.

ii. *Single negative point charge:*



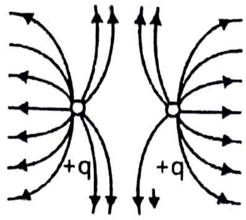
- ✓ In this case electric field lines are radially inward.

iii. *Two equal and opposite point charges:*



- ✓ The electric field lines are curved in this case and they are directed from positive charge to the negative charge.

iv. *Two equal positive point charges:*



- ✓ In this case the electric field lines exerts lateral pressure which cause repulsion between them.
- ✓ There exists neutral point or null point between them where electric field intensity is zero.
- ✓ If they are of same magnitude then $F_1 = F_2$.
- ✓ But if they are of unequal magnitude then according to relation;

$$\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2}$$

then the neutral point N will be closer to the smaller charge

v. **Parallel plate capacitor:**

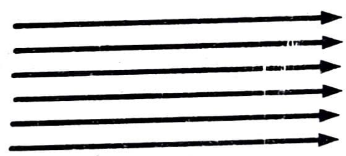
- ✓ In this case electric field lines are parallel and equally spaced except near the edges.
- ✓ Thus, in central region, $\vec{E}$ is same or constant. ***(called uniform field will be explained later)***
- ✓ Although, the field fringes near the edges. We often ignore it if separation of a plate is small as compared to size.

Relation between $\vec{E}$ and Electric field lines:

$E_n \propto \frac{n}{4\pi r_n^2} \Rightarrow \frac{E_1}{E_2} = \frac{r_2^2}{r_1^2}$ *i.e.* $E \propto \frac{1}{r^2}$ *This implies that electric field intensity is greater near the charge*

FOR UNIFORM FIELD THIS RELATION; $E \propto \frac{1}{r^2}$ *not applicable*

Uniform Field:



- ✓ If electric field is constant both in magnitude as well as direction.
- ✓ Represented by $\vec{E} = constant$.
- ✓ Uniform field is produced by central region of parallel plate capacitor.
- ✓ Note that single isolated charge cannot produce uniform field.
- ✓ For uniform field the relation $E \propto \frac{1}{r^2}$ is not applicable.
- ✓ Uniform field is represented by parallel equal-space lines.
- ✓ In given diagram the space between arrow is same, this represents uniform field.

Motion of Charged Particle in an Electric Field:

⇒ **When charged particle initially at rest is placed in the uniform field:** Let a charge particle of mass m and charge Q be initially at rest in an electric field of strength E

i. **Force and acceleration:** The force experienced by the charged particle is F = QE. Positive charge experiences force in the direction of electric field while negative charge experiences force in the direction opposite to the field.

Acceleration produced by this force is $a = \frac{F}{m} = \frac{QE}{m}$

Since the field E in constant the acceleration is constant, thus motion of the particle is uniformly accelerated.

ii. **Velocity:**

$$v = \frac{QEt}{m} \quad or \quad v = \sqrt{\frac{2QV}{m}}$$

iii. **Distance travelled by particle is S,** $S = \frac{1}{2}at^2 = \frac{1}{2}\frac{qE}{m}t^2$

iv. **Momentum:**

$$P = \sqrt{2mQV}$$

v. **Kinetic energy:**

$$K.E = \frac{1}{2}mv^2 \Rightarrow \frac{Q^2E^2t^2}{2m} = QV$$

vi. If a charged particle is entering the electric field in perpendicular direction then its path will be parabolic.

Electric flux

⇒ In general flux stands for 'Flow rate'.

⇒ Electric flux through a given area in an electric field represents the total number of electric lines of force crossing the area.

⇒ It is scalar quantity.

⇒ It is represented by ϕ_E.

⇒ It may be also defined as 'the dot product of electric field strength $\vec{E}$ and area perpendicular to the field'.

⇒ **Mathematically;**

$$Electric\ flux \Rightarrow \phi = \vec{E}.\vec{A} = EAcos\theta$$

$$The\ area\ \vec{A}\ is\ a\ vector\ area$$

⇒ θ is the angle between ***normal unit vector*** and ***electric flux intensity***.

⇒ *Note that $\phi = EA$ this equation is only applicable for flate area, or Vector area*

⇒ ***We can also write equation of electric flux in form of;***

$$\phi = EA\sin\alpha$$

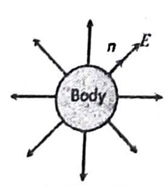
$$\alpha = angle\ between\ surface\ area\ and\ \vec{E}$$

⇒ We cannot use the equation $\vec{E}.\vec{A}$ to calculate flux through closed surface.

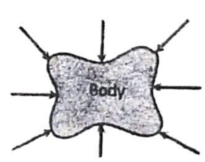
⇒ **Unit:** $NC^{-1} \times m^2 = Nm^2C^{-1}$

⇒ **Dimension:** $\phi = E \times S = \frac{F}{q} \times S \Rightarrow \frac{[MLT^{-2}]}{[AT]}[L^2] = [ML^3T^{-3}A^{-1}]$

⇒ ***Types: For a closed body outward flux is taken to be positive, while inward flux is to be negative***



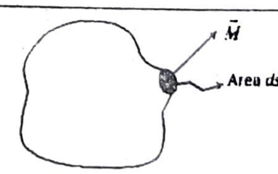
Positive – flux
(A)



Negative-flux
(B)

⇒ *Vector area*

Area is a <u>scalar quantity</u>. But in in many cases, it is convenient to treat area of a surface as a vector. The length of the vector represents the magnitude of the area and its direction is along the outward drawn normal to the area.



⇒ *From above equation it is clear that;*

⇒ $\phi \propto E \Rightarrow As\ E = \frac{kq}{r^2}$

⇒ $so\ \phi \propto q$

⇒ $\phi \propto \frac{1}{\epsilon_{medium}}$

⇒ $\phi \propto \frac{1}{r^2}$

$$\phi \propto A$$

Some important cases in Electric flux;

Condition	Flux

$if\ \theta = 0°$ between E and A	Maximum ($\phi = +ve$)
$if\ \theta = 90°$ between E and A	Zero
$if\ \theta = 180°$ between E and A	$\phi = -EA$ (i.e.. flux = negative)

From above all discussions we conclude that there are three methods of finding magnitude of $\vec{E}$;

- $E = \frac{F}{q_o}$ (Test charge method)
- $E = \frac{kq}{r^2}$ (Source charge method)
- $\phi = EA \Rightarrow E = \frac{\phi}{A} \rightarrow$

Without using source charge or test charge we can find E through this equation
This can be defined as; the ratio of ϕ with A and that is actually field lines density.

Gauss's Law

⇒ It is actually generalized form of Coulomb's law.

⇒ But it must be note that Coulomb law is for Point charges and Gauss's law is for all point as well as other distribution of charges.

⇒ Gauss's law gives us more information than coulomb's law.

⇒ Gauss's law tells us "the total electric flux passing through a closed surface is equal to $\frac{1}{\epsilon_o}$ times the net charge enclosed by the closed surface.

⇒ Here ϵ_o is absolute permittivity of free space or vacuum.

⇒ If q is charge enclosed by surface then according to gauss's law flux is given by;

$$\Phi = \frac{q}{\epsilon_o}$$

⇒ Gauss's law may be stated as, 'if a closed surface enclosed charge (q) then surface integral of electric field ($\vec{E}$) over the closed surface is equal to $\frac{1}{\epsilon_o}$ times the charge enclosed.

⇒ Gauss's law is valid for symmetrical charge distribution.

⇒ Note that the charges inside the closed surface may be point as well as continuous charge distribution.

⇒ The location of charge or charges inside the closed surface does not matter.

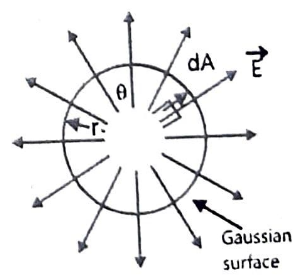
⇒ The shape of the surface does not matter provided it is a closed surface enclosing the charge or charges.

⇒ If the medium surrounding the charge has a relative permittivity ϵ_r then;

$$\Phi = \frac{q}{\epsilon_r \epsilon_o} = \frac{q}{\epsilon} \quad where\ \epsilon_r = \frac{\epsilon}{\epsilon_o}$$

⇒ The charges outside the closed surface make no contribution to the total electric flux over the surface.

⇒ Gauss's law is very helpful in calculating electric field in those cases where electric field is symmetrical around the source producing it.



⇒ Electric field can be calculated very easily by the clever choice of a closed surface that encloses the source charges. Such a surface is called "Gaussian surface". This surface should pass through the point where electric field is to be calculated and must have a shape according to the symmetry of source.

⇒ If suppose a charge Q is placed at the center of a hemisphere, then to calculate the flux through this body, to encloses the first charge we will have to imagine a Gaussian surface. This imaginary Gaussian surface will be a hemisphere as shown.

Net flux through this closed body $\phi = \frac{Q}{\epsilon_o}$

Hence flux coming out from given hemisphere is $\phi = \frac{Q}{2\epsilon_o}$

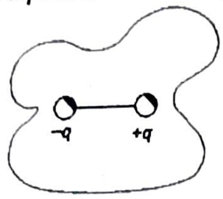
Gaussian surface;

- It is hypothetical surface.
- It is chosen to calculate the surface integral of electric field.
- The gaussian surface can be any of shape but the most useful surface is one upon which integral of electric field can be taken easily.

- The most commonly used gaussian surface is sphere.
- In all gaussian surfaces electric field intensity at all points on the surface is same and electric flux through the surface is along the normal to the surface at every point on the surface.

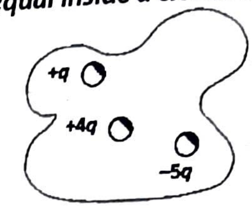
⇒ **Zero flux:** The value of flux is zero in the following circumstances

(i) If a dipole is enclosed by a surface



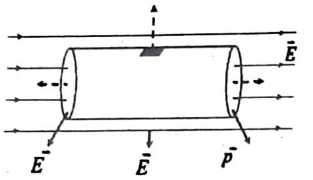
$\phi = 0, Q_{enclosed} = 0$

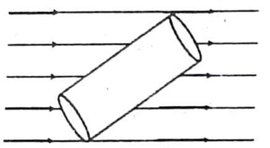
(ii) If the magnitude of positive and negative charges are equal inside a closed surface



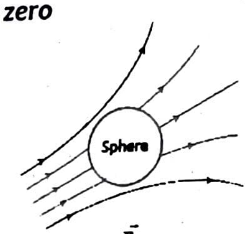
$\phi = 0, Q_{enclosed} = 0$

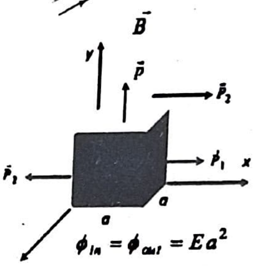
(iii) If a closed body (not enclosing any charge) is placed in an electric field (either uniform or nonuniform) total flux linked with it will be zero





$\phi_T = 0$





$\phi_{in} = \phi_{out} = Ea^2$

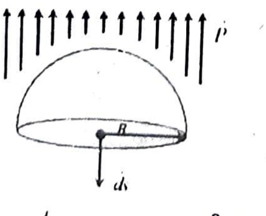
If there are n point charges $q_1, q_2, q_3 \dots\dots\dots\dots q_n$ lying inside the surface, then according to superposition principle each charge will contribute to electric flux independent of each other;

$$\phi_E = \phi_1 + \phi_2 + \phi_3 - - - - - - + \phi_n$$
$$= \frac{q_1}{\epsilon_o} + \frac{q_2}{\epsilon_o} + \frac{q_3}{\epsilon_o} \pm - - - - + \frac{q_n}{\epsilon_o}$$
$$\frac{1}{\epsilon_o}(q_1 + q_2 + q_3 + - - - q_n) = \frac{q}{\epsilon_o}$$

$$q = \sum_{i=1}^{i=n} q_i = Algebric\ sum\ of\ charge\ inside\ the\ closed\ surface$$

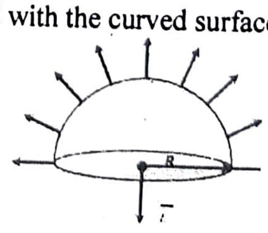
Some important interpretations

i. If a hemispherical body is placed in uniform electric field then flux linked with the curved surface



$\phi_{curved} = +\pi R^2 E$

i. If a hemispherical body is placed in non-uniform electric field as shown below. Then flux linked with the curved surface.



$\phi_{curved} = 2\pi R^2 E$

ii. If $q_{enclosed} = + \Rightarrow \Phi_{total} = +ve$

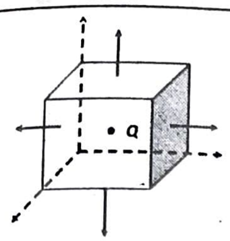
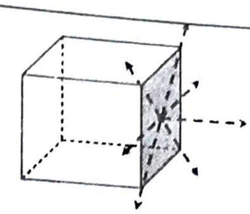
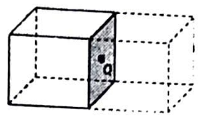
$$\phi_{Total} = \frac{+q_{enclosed}}{\epsilon_o}$$

ii. If $q_{enclosed} = - \Rightarrow \Phi_{total} = -ve$

$$\phi_{Total} = \frac{-q_{enclosed}}{\epsilon_o}$$

iii. If charge is kept at the center of cube

iii. If charge is kept at the center of a face

 $\phi_{total} = \frac{1}{\epsilon_o}.(Q)$ $\phi_{face} = \frac{Q}{6\epsilon_o}$ $\phi_{corner} = \frac{Q}{8\epsilon_o}$ $\phi_{edge} = \frac{Q}{12\epsilon_o}$	 First, we should enclose the charge by assuming a Gaussian surface (an identical imaginary cube) $\phi_{total} = \frac{Q}{\epsilon_o}$  $\phi_{cube} = \frac{Q}{2\epsilon_o}(i.e. from\ 5\ face\ only)$ $\phi_{face} = \frac{1}{5}(\frac{Q}{2\epsilon_o}) = \frac{Q}{10\epsilon_o}$
iv. If $no\ of\ field\ lines\ leaving = no\ of\ field\ lines\ entering$ $then;\ \phi_{net} = 0\ and\ q_{enclosed} = 0$	iv. If $no\ of\ field\ lines\ leaving > no\ of\ lines\ entering$ $then;\ \phi_{net} = +ve$ $and\ q_{enclosed} = +ve$
v. If $no\ of\ field\ lines\ entering > no\ of\ lines\ leaving$ $then;\ \phi_{net} = -ve$ $and\ q_{enclosed} = -ve$	v. If we want to find the total charge enclosed and flux outside the gaussian surface then in this case; $\phi = 0\ and\ q_{enclosed} = 0$
vi. If net charge or total charge enclosed by gaussian surface is zero then; $\phi = 0\ and\ q_{enclosed} = 0$	vi. If $no\ of\ field\ lines\ leaving = no\ of\ lines\ entering$ $\phi = 0\ and\ q_{enclosed} = 0$

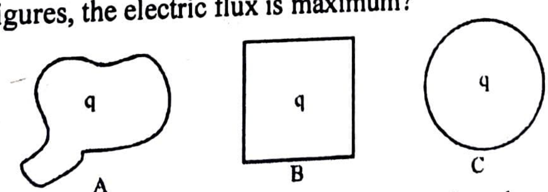
Important point:

i. In C.G.S $\epsilon_o = \frac{1}{4\pi}$ Hence if 1C charge is enclosed by a closed surface so flux through the surface will be $\phi = 4\pi$.

ii. The net flux of the electric field through a closed surface due to all the charges lying inside or outside the surface is equal to the flux due to the charges only enclosed by the surface.

iii. The electric flux through any closed surface does not depend on the dimensions of the surface but it depends only on the net charge enclosed by the surface.

iv. In which of the following figures, the electric flux is maximum?



According to Gauss's law, the electric flux linked with a closed surface depends only on net charge enclosed be that surface. It does not depend on the shape and size of that closed surface. Hence electric flux linked in above three figures are same i.e., $\phi_A = \phi_B = \phi_C$.

Applications of Gauss's law

i. **Electric field outside the shell: It is given by equation**

$$E = \frac{q}{4\pi\epsilon_o r^2}$$

✓ So, the electric field intensity at any point outside a uniformly charged spherical shell is same as if all the charge were concentrated as a point charge at the center of the shell.

ii. **Electric field on the surface of shell: it is given by equation;**

$$E = \frac{\sigma}{\epsilon_o}$$

iii. **Electric field inside the shell:**

✓ Electric field due to a uniformly charged spherical shell is zero at all points inside the shell $E = 0$.

✓ Note that going outside the shell $E \propto \frac{1}{r^2}$ is followed.

iv. ***Electric field outside the solid sphere:***
The electric field intensity at any point outside the uniformly charged non-conducting solid sphere is same as through the entire charge were concentrated at the center of a solid sphere.

v. ***Electric field inside the solid sphere:***
Electric field intensity at any point inside the uniformly charged non-conducting solid sphere varies directly as the distance of a point from the center of the solid sphere.

vi. ***Electric field at the Centre solid sphere:***
Electric field intensity at the center of uniformly charged non-conducting solid sphere is zero.

vii. ***Electric field intensity due to an infinite sheet of charge:***

⇒ The value of electric field intensity due to an infinitely sheet of charge is given by;

$$E = \frac{\sigma}{2\epsilon_o}$$

$$\vec{E} = \frac{\sigma}{2\epsilon_o}\hat{r} \ (vector\ form)$$

⇒ So clearly E in this case is independent of r.

⇒ If the sheet carries positive charge the electric field is uniform and points normally away from the plane charged sheet on its both sides.

⇒ If the sheet carries negative charge, electric field is uniform and points normally into the plane sheet on both sides.

⇒ In case of an infinite plane conductor having finite thickness (e.g. metal plate), the gaussian surface will includes charge equal to $\sigma \times 2A$ $(\sigma A\ is\ charge\ on\ each\ surface\ of\ the\ conductor)$

$$E \times 2A = \frac{\sigma \times 2A}{\epsilon_o} \quad or\ E = \frac{\sigma}{\epsilon_o}$$

viii. ***Electric field intensity between two oppositely charged parallel plates:***

⇒ The electric field intensity between two oppositely charged parallel plates is given by;

$$E = \frac{\sigma}{\epsilon_o}$$

$$\vec{E} = \frac{\sigma}{\epsilon_o}\hat{r} \ (Vector\ form)$$

⇒ The electric field intensity between two sheets having equal and opposite uniform surface charge densities is constant $(= \frac{\sigma}{\epsilon_o}$ and is directed from the positive to the negative sheet.

⇒ while the field is zero on the outside of the two sheets.

⇒ This arrangement is used for producing uniform electric field.

We use this equation $E = \frac{\sigma}{\epsilon_o}$ when $\sigma_1 = \sigma_2$

For $\sigma_1 \neq \sigma_2$ we use equation $E = \frac{\sigma_1}{\epsilon_o} + \frac{\sigma_1}{\epsilon_o}$

Note:

Electric field intensity between two oppositely charge sheet $= 2\,\vec{E}$ *single sheet*

$$E_{two\ single\ sheet} = \frac{\sigma}{2\epsilon_o}$$

$$E_{two\ oppositely\ charged\ sheet} = 2\left(\frac{\sigma}{2\epsilon_o}\right)$$

$$E_{two\ oppositely\ charged\ sheet} = 2E_{single\ sheet}$$

$$\frac{E_{t \cdot o}}{E_{single}} = 2:1$$

Electric potential energy

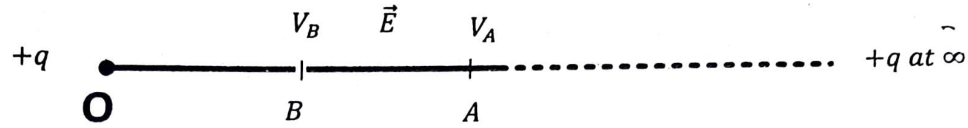
⇒ As mass has potential energy in the gravitational field since electric charge has electrostatic potential energy in electrostatic field.

⇒ It can be defined as 'if we move unit positive test charge of same magnitude in equilibrium against electric field then work done on unit positive test charge can be stored in the form of energy, that is actually called electric potential energy'.

⇒ It is represented by ΔU.

⇒ From this concept we know that electric field is a conservative field, because potential energy are defined only for conservative field.

⇒ This shows that work done is zero around the closed path.



From figure above, we conclude same points;

✓ The charge q sets up electric field which theoretically extends up to infinity.

✓ If a small positive test charge $+q_o$ is placed at infinity, then potential energy of $+q_o$ is zero.

✓ As the test charge that is actually at infinity is moved towards $+q$ work will have to be done against electrostatic force of repulsion, because they are like charges.

✓ This work done is stored in the form of electric potential energy.

✓ Note that the charge must be moved with uniform velocity.

⇒ Potential energy of $+q_o$ at point A:

$$U_A = W_{\infty A} = \text{this is work done in bringing } + q_o \text{ from infinity to point } A$$

⇒ Potential energy of $+q_o$ at point B:

$$U_B = W_{\infty B} = \text{this is work done in bringing } + q_o \text{ from infinity to point } B$$

⇒ Clearly $U_B > U_A$ this shows that potential energy at point B is greater than that at point B.

What will happen if we move the charge from infinity to point A or B non-accelerated or non-uniformly?
Answer: it will lose energy in the form of electromagnetic waves.

Electric potential

⇒ Electric potential can be defined as "the potential energy per unit charge".

⇒ According to work energy theorem (work done = energy) so it may be defined as "the work done in moving a positive test charge from infinity to that point".

⇒ So, from figure above;

$$\text{Electric potential at } A, V_A = \frac{W_{\infty A}}{q_o} = \frac{U_A}{q_o}$$

$$\text{Electric potential at } B, V_B = \frac{W_{\infty B}}{q_o} = \frac{U_B}{q_o}$$

⇒ Clearly $V_B > V_A$.

⇒ If $+q_o = 1$ then, $V_A = W_{\infty A}$ and $V_B = W_{\infty B}$

⇒ It is represented by V.

⇒ As $V = \frac{\text{Work done}}{\text{Charge}}$ since work done and charge are scalar, so electric potential is a scalar quantity.

⇒ Note that electric field may be describes in terms of vector or scalar.

⇒ In terms of vector it is represented by $\vec{E}$ but in terms of scalar it is represented by electric potential V.

⇒ The potential energy of a charge q at a point where potential is V is given by;

$$P.E \text{ of } q = qV$$

⇒ **SI Unit:**

As $V = \frac{\text{Work done}}{\text{Charge}}$

The Si unit of a work done is 1 J and that of charge is 1 C, therefore Si unit of electric potential V is J/C which is also called volt.

⇒ **Dimension of electric potential:**

$$V = \frac{\text{Workdone}}{\text{Charge}} \Rightarrow \frac{[ML^2T^{-2}]}{[AT]} = [ML^2T^{-3}A^{-1}]$$